IFM-GEOMAR

Leibniz-Institut für Meereswissenschaften
an der Universität Kiel

IFM-GEOMAR Report 2002-2004

From the Seafloor to the Atmosphere

- Marine Sciences at IFM-GEOMAR Kiel -

June 2005

Preface

For the first time, the Leibniz Institute of Marine Sciences (IFM-GEOMAR) presents a joint report of its research activities and developments in the years 2002-2004. In January 2004 the institute was founded through a merger of the former Institute for Marine Research (IfM) and the GEOMAR Research Center for Marine Geosciences. This report addresses friends and partners in science, politics and private enterprises. It gives an insight into the scientific achievements of IFM-GEOMAR and its predecessor institutes during the last three years.

3.11 New Approaches to the Dynamics of Fish and Squid Populations

Many exploited stocks of fish and squid undergo large fluctuations or extended trends in population size on different time scales, related to environmental changes as well as to fishing pressure. Therefore, one major aim of fishery biology is to understand the mechanisms regulating these stock fluctuations and to develop methods to predict the effects of fishery on exploited stocks and ecosystems in total as well as the effects of natural environmental fluctuations and climate trends on the exploitable production. The complexity of the task is increased by the fact that natural and manmade effects are strongly interlinked and cannot be considered separately. One aspect of crucial importance is the reproductive strategy of exploited stocks which is in many species adapted to a highly variable environment, based on extremely high fecundities and diversities in stock structures, which includes the chances for population survival over periods of unfavourable conditions as well as the development of large stock sizes under favourable conditions. The regional stock structure, the size and age structure of the spawning stocks, both influenced by fishery, the nutritional condition of adults and thus the quality of gametes and the survival of the early life stages related to stock structure, abiotic environment and presence of prey and predators are the key factors determining the reproductive success of a species. One focus of the Research Unit Fishery Biology is to improve the knowledge on the most relevant factors governing the recruitment processes in fish and squid stocks by the development of new methodical approaches, which allow to elucidate the characteristics of survivors during early development and to address also behavioural patterns that provide best likelihood for survival. For this purpose the growthhistory and the chronology of important events during the early development of individual fish have to be considered. This can be supported by analysing the optical and chemical microstructures of fish otoliths or statoliths in squids, combined with new methods in survey strategies, drift modelling, biochemical identification of nutritional conditions, utilization of experimental results on physiology and behaviour for individual based modelling of survival success. Examples for corresponding activities are presented below.

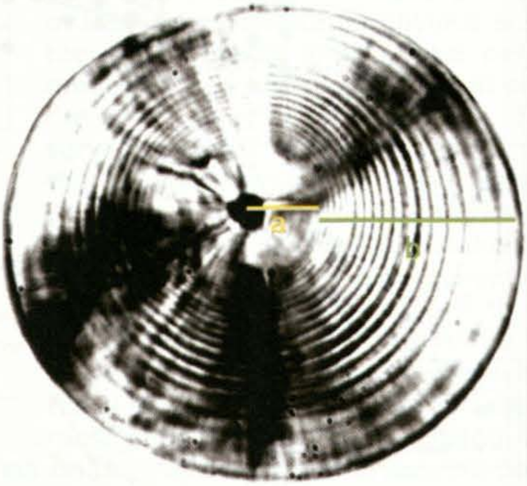

Figure 1: Sprattus sprattus otolith. (a. embryonic phase, b. larval growth zone with daily increments)

Figure 1 depicts an otolith of a larval sprat (*Sprattus sprattus*). The inner part of the otolith refers to the embryonic life phase (a.), while the part marked with "b" corresponds to the larval phase. In this part several rings are easily detectable. Each increment represents one day in a larva's life and consists of a "white" and a "dark" zone. The white zone is formed during phases of high metabolic rates and somatic growth, while the dark zone corresponds to resting periods or reduced metabolic activity. Thus, the alternation of both zones reflects typical daily activity patterns. The number of rings provide information on age, and the widths of daily as well as annual rings reflect individual growth patterns, so that individual growth histories can be obtained from otolith analysis, which is of special interest for the early larval development. In addition, the trace element composition in otoliths can be utilized to provide information on the ambient environmental conditions like water temperature and salinity, and high resolution analysis techniques allow to relate this information to age and growth based on the ring structure of the otoliths. Thus, otoliths/statoliths can be regarded as an archive recording the life history. Reading this archive, provides important information to identify characteristics of survivers and environmental conditions they were exposed to.

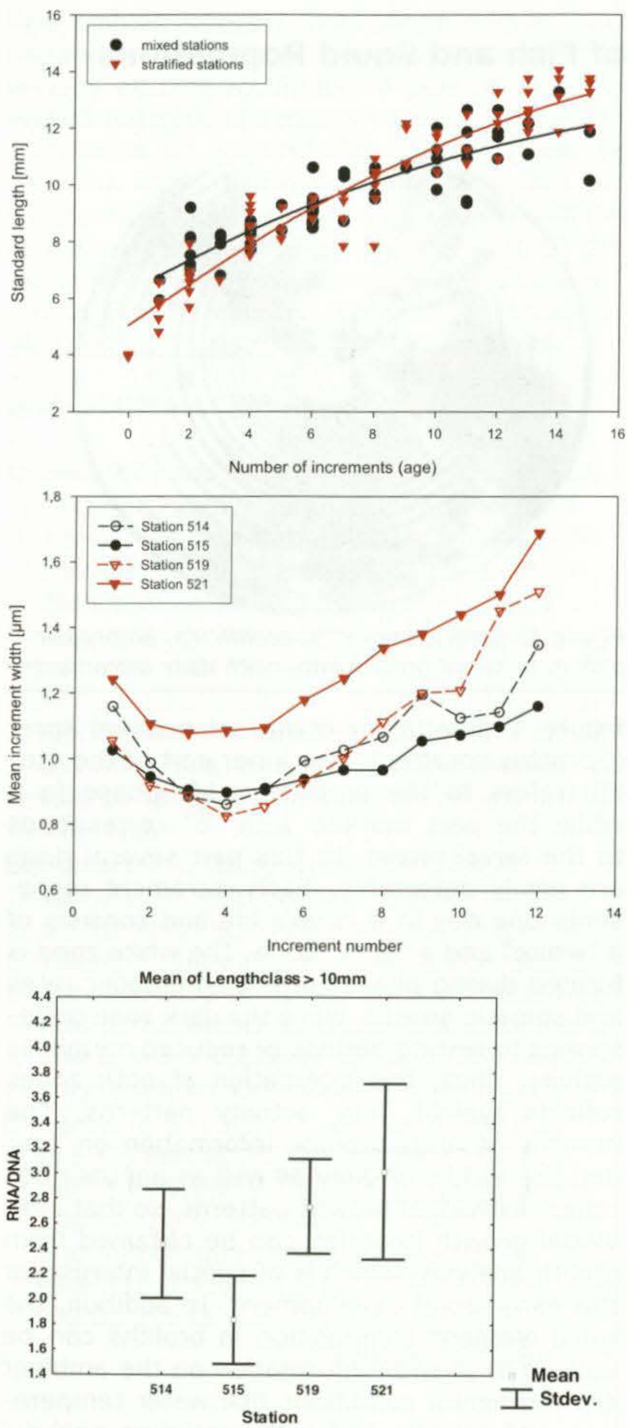

Figure 2: Comparison of size at age (apparent growth rate within the population, upper panel) and mean increment width (average and variation of individual growth rates, middle panel) of sprat and sardine larvae sampled from a tidal mixing front in the German Bight. Stations 514, 515 represent the mixed water body, stations 519, 521 the stratified water body. The lower panel indicates the mean and standard deviation of the RNA/DNA ratios reflecting protein metabolism as a measure of feeding activity determined from the same larvae caught at the different stations.

Larval Growth and Nutritional Condition in Relation to Environmental Conditions

Otolith analysis have been applied to study variations in growth and nutritional condition of fish larvae and the impact of hydrographic features like frontal systems. As an example Figure 2 presents growth rates and a biochemical measure for nutritional condition in a mixed population of sprat (*Sprattus sprattus*) and sardine (*Sardina pilchardus*) larval sampled on 4 stations across a tidal mixing front in the German Bight.

By relating size of the larvae to number of increments (age), the average growth rates within the sampled populations have been determined and compared between the mixed and stratified area (Fig. 2, upper left panel). Highest growth rates were found at the stratified water stations offshore. The results from this traditional approach may have been influenced by size selective mortality and, as it is based on a single survey and is not following the development of hatch-time cohorts, they also may have been effected by differences in the initial size of larvae. In this case some slight indication is given for a larger initial size in the mixed area.

Using increment width from otoliths provides a measure of actual daily growth rates for those individuals which have survived until the time of sampling (Fig. 2, upper right panel). These data confirm differences in growth among stations with all larvae from one station and the later larval stages from both stations of the stratified water body showing larger increment widths compared to the mixed area. These growth differences were related to higher chlorophyll concentrations and indicate higher abundance of larval food.

The assumption about food availability and consumption as basis for the observed growth differences can be verified by comparison with a biochemical index of nutritional condition measured from the same larvae. Fig. 2, lower panel presents average RNA/DNA ratios per station, reflecting protein metabolism as a measure of feeding activity. These ratios, which relate only to the conditions a short time prior to sampling, show the same ranking among stations as can be seen among the individual growth rates of the later larval stages, confirming the differences in food availability at about the time of sampling.

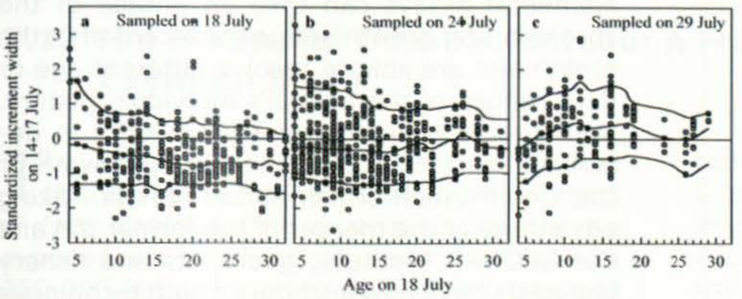

Figure 3: Standardized otolith increment widths as relative measure of individual daily growth rates, obtained for a population of radiated shanny larvae sampled at three successive dates. The lines show the 10^{th}, 50^{th}, and 90^{th} percentiles of the cumulative probability distribution. Shifts between survey dates in the growth rate distribution per age group indicate size selective mortalities.

Size Selective Mortality

Differences in the average individual growth rates of larval cohorts surviving to a later stage of development may be influenced by mortality again, which complicates the interpretation of growth data, but also allows to identify size selective mortality effects, when the same population of larvae is sampled by repeated survey.

Figure 3 presents an example of results on individual growth from a comprehensive cooperative study on the development of larval radiated shanny (*Ulvaria subbifurcata*) in a large bay of Newfoundland. In order to allow a comparison of the variation and shift in daily growth rates for larval cohorts of different age, the otolith increment width data are presented in a standardized form, as deviations from the mean over time for each daily age group. The results presented in the figure indicate an obvious shift in the distribution of growth rates per age group towards higher values from one to the next survey and thus for the longer surviving part of the cohorts. It illustrates that slower growing individuals were exposed to higher mortalities during this study, which was most pronounced for the oldest larvae in the period between the first and second survey and for mid aged larvae from the second to the third survey. It could be judged from additional information that predation was the most important factor, depending in its effect on the distribution of larvae and predators combined with temperature related spatial differences in the growth characteristics.

Identification of Feeding Habitats

Simulations with a coupled biophysical model of the Baltic Sea have been performed in order to enable the reconstruction of the environmental conditions (temperature, prey) sprat larvae had been exposed to during their development. By comparing these environmental conditions with the growth histories of sprat larvae based on otolith increment width, it was possible to define areas where these larvae had encountered suitable feeding conditions. Temperature and prey ingestion have been considered as

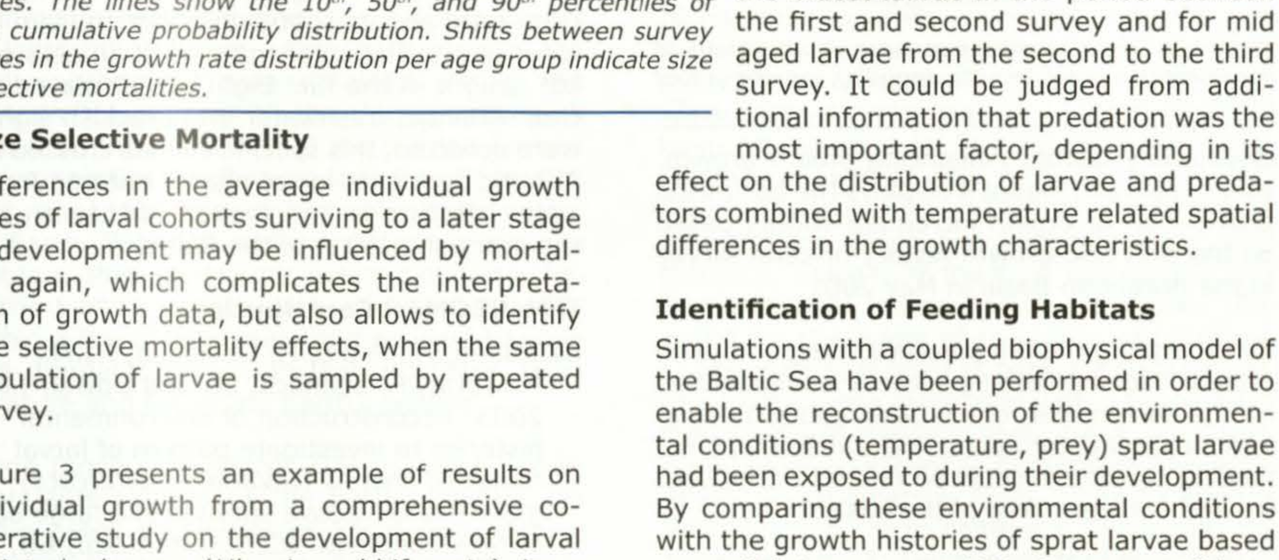

Figure 4: Horizontal distribution of otolith increment widths of sprat larvae in the Bornholm Basin in May 2001 (left panel). By separating the temperature effect on otolith growth, highest feeding success was observed especially in the eastern part of the basin, whereas less optimal feeding conditions could be related to the centre and northern area of the basin (right panel).

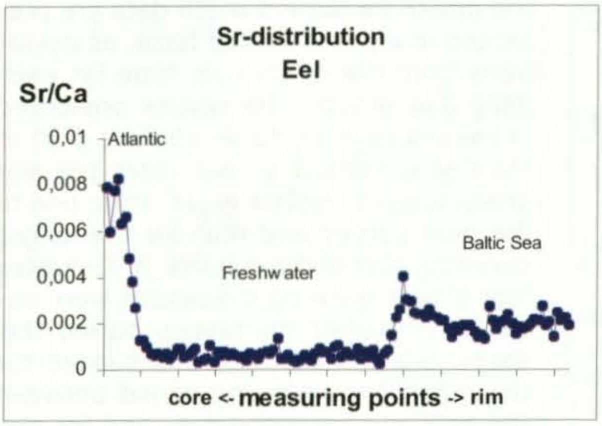

Figure 5: Strontium/Calcium ratio of an otolith of the European eel (Anguilla anguilla), caught in Kiel Bight.

driving key factors influencing otolith growth. As an example, Figure 4 displays the horizontal distribution of otolith increment widths based on the drift and growth history of sprat larvae in the Bornholm Basin in May 2001.

By separating the temperature effect on otolith growth, highest feeding success was identified for the eastern part of the basin and somewhat less for the western part, whereas less optimal feeding conditions could be related to the centre and northern area of the basin.

Detection of Migration Routes and Pathways

The trace element composition of hard structures, such as fish otoliths and statoliths of cephalopods is influenced by, e.g., ambient water temperature and salinity. Trace element composition in combination with age readings provide a powerful tool to reconstruct life history events and migration pathways of individual specimen.

Presently two different methods to determine the trace element distribution are applied by the fishery biology group in cooperation with geologists: The Synchrotron X-ray Fluorescence Analysis (SYXRF) and the use of an electron microprobe. In the marine geochemistry group at IFM-GEOMAR, electron microprobe and X-ray Flurescense analyses have frequently been applied to investigate, e.g., plate tectonic processes. The excellent micro-scale resolution and the precise analysis of elements from Calcium (Ca) to Lead (Pb) makes SYXRF a very accurate tool to gather life history information of fish and cephalopods from their otoliths and statoliths, respectively. Beam-based elemental assays can take advantage of the chronological growth sequence recorded in the otolith and are able to resolve different age or date ranges of the animal's individual history. Both methods are extremely powerful in describing fish migration routes and pathways or the identification of fish nursery areas. Taking advantage of the merger of the former IfM and the GEOMAR Institute, geologists and fishery biologists have now introduced both techniques to address questions related to fish behaviour.

As an example, in Figure 5 the strontium/calcium ratio and its spatial distribution from the inner part to the outer margins of an eel's otolith caught in the Kiel Bight are displayed. As clear Atlantic, freshwater and brackish signals were detected, this specific eel has crossed the Atlantic during its larval phase, entered freshwater afterwards and moved further on into the brackish habitat of the Baltic.

IFM-GEOMAR Contributions

Baumann, H., Pepin, P., Davidson, F.J.M., Mowbray, F., Schnack, D., and Dower, J.F., 2003: Reconstruction of environmental histories to investigate pattern of larval radiatied shanny (*Ulvaria subbifurcata*) growth and slective survival in a large bay of Newfoundland. *ICES J. Mar. Sci.*, **60**, 243-258.

Hinrichsen, H.-H., Lehmann, A., Möllmann, C., and Schmidt, J.O., 2003: Dependency of larval fish survival on retention/dispersion in food limited environments: The Baltic Sea as a case study. *Fish. Oceanogr.*, **12**, 425-433.

Huwer, B., 2004: Larval growth of Sardina pilchardus and Sprattus sprattus in relation to frontal systems in the German Bight. Diplomarbeit, Universität Kiel, 107 pp.

Köster, F.-W., Hinrichsen, H.-H., Schnack, D., St. John, M.A., MacKenzie, B.R., Tomkiewicz, J., Möllmann, C., Kraus, G., Plikshs, M., Makarchouk, A., and Aro, E., 2003: Recruitment of Baltic cod and sprat stock: identification of critical life stages and incorporation of environmental variability into stock-recruitment relationships. *Sci. Mar.*, **67** (Suppl. 1), 129-154.

Schröder, J., 2004: Der Einfluss von Umweltfaktoren auf die chemische Mikrostruktur von Fischotolithen. Diplomarbeit, Universität Kiel, 114 pp.

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